

## **UNDERWATER WAVE/ENERGY TRANSDUCER**

### **BACKGROUND OF THE INVENTION**

#### **1. Field of the Invention**

5 This invention relates to devices for converting ocean wave action to electrical current as a useful energy source. More specifically, the invention pertains to underwater devices which are positioned at the ocean floor and respond to changes in wave height to supply variable pressures or water movement at the transducer.

#### **2. Related Art**

10 The abundance of energy contained in ocean waves has long been recognized. It has been estimated that over 20,000 km of coastline throughout the world may be suitable for harnessing wave power for conversion to electrical power by means of some type of power transducer. In systems close to the shore, the estimated average energy available is approximately 40 to 70 kW per meter of shoreline in energy rich coastal areas, and approximately 10 to 20 kW/m in areas of lesser wave activity. This  
15 extensive power resource has been acknowledged by a number of countries, as well as several private industries. Several large power installations have been constructed in an effort to capitalize on this renewable energy source.

20 Despite much effort and some recent progress, extracting this energy in a practical, cost effective system remains a formidable challenge. The difficulty of energy conversion within the ocean environment arises from the rather hostile conditions that must be overcome. For example, the saltwater conditions are chemically aggressive and contain marine life that result in biofouling of the operating system, further adding to the dynamic state of unpredictable change. In addition to  
25 salt water, sand and marine life, weather conditions can generate extreme conditions, particularly at ocean surfaces and shoreline. Storm activity and winds have destroyed countless devices that have endeavored to extract energy from wave movements at the ocean surface, requiring high costs of maintenance and replacement that have labeled wave energy technology as generally uneconomical.

30 The parent patent leading to the present invention disclosed a variety of devices that are positioned on the ocean floor, preferably at depths between 5 and 30 meters, significantly reducing exposure to adverse weather and wind conditions. As

waves move above the device, the water level changes, causing a pressure differential to be variably applied to the transducer. These pressure changes register at the transducer and are converted by electro-mechanical devices into electricity. Several of the disclosed devices include coil/magnet combinations as the operative component for changing mechanical movement into electrical current. This current is transmitted to a shore location for storage in a battery pack or other location for use.

### **SUMMARY OF THE INVENTION**

The present invention provides an energy transducer device for positioning at the ocean floor for converting wave action at an ocean surface above the transducer to electrical current. The device comprises a mounting base configured for positioning at the ocean floor below a location of possible wave action wherein the wave action generates a water displacement or surge toward or along a horizontal flow path in response to an alternating pressure differential caused by the wave action. An electro-mechanical transducer is coupled to the mounting base and is configured for positioning within the surge or flow path and responsive to water movement to generate electrical current.

An additional embodiment includes an elongate tube oriented in the direction of wave propagation that provides a reciprocating flow path for fluid, such as ocean water. An electro-mechanical device having fins or other resistive structure is positioned within the flow path and moves in response to the water movement within the tube to generate current. Water movement is driven by pressure differentials experienced at opposing ends of the tube, such as where one end is disposed under a wave crest and the opposing end stands under a trough. Gravity will tend to displace water at the crest end of the tube to the lower pressure trough end. Such water movement or resulting pressure moves or turns the fins of the electro-mechanical device for electrical production. Reciprocating movement arises as the wave action moves across the length of the tube, alternately positioning the crest and trough over the opposing ends of the tube. By inverting fin orientation within the electro-mechanical device to accommodate reverse flow directions, the electro-mechanical device rotation remains in a substantially constant direction.

Numerous other embodiments are disclosed herein, more generally illustrating the scope of the invention. Other configurations will also be apparent to those skilled in the art, based on the following detailed description and accompanying drawings.

### **DESCRIPTION OF THE DRAWINGS**

Figure 1 shows a side view of a preferred embodiment of the invention.

Figure 2 illustrates an alternative configuration disposed under the respective crest and trough of an ocean wave.

Figure 3 depicts a side view of an additional embodiment of the invention including a piston element.

Figure 4 graphically illustrates reciprocating surge activity within the ocean.

Figure 5 shows a side plan view of a further embodiment of the invention.

Figure 6 depicts an elevated perspective view of an isolated displacement plate in accordance with one embodiment of the invention.

Figure 7 illustrates a side view of a tracking version of the present invention.

Figure 8 provides an elevated perspective view of a rotational plate in accordance with one embodiment of the invention.

Figure 9 provides an elevated perspective view of an additional rotational plate in accordance with one embodiment of the invention.

Figure 10 provides an elevated perspective view of a unidirectional rotational configuration in accordance with one embodiment of the invention.

Figure 12 provides a side perspective view of an additional rotational configuration in accordance with one embodiment of the invention.

Figure 13 graphically illustrates a variation of Figure 10 with a hinged or flexible member to reduce losses.

Figure 14 depicts a folded configuration of the Figure 13 embodiment.

Figures 15 a, b, and c show perspective views of a multidirectional movement transducer capable of responding to water displacement from any direction.

### **DESCRIPTION OF PREFERRED EMBODIMENTS**

The parent application focused on several of the preferred embodiments that were generally oriented in a vertical configuration. These structures were positioned to respond to direct weight or movement of overhead water applied to a pressure

plate. Changes in water height based on surface wave action resulted in a pressure differential that could thus be converted by a transducer to electrical current.

The present application primarily illustrates embodiments of the invention applied in a substantially horizontal orientation above the ocean floor. It will be  
5 apparent to those skilled in the art that the actual orientation of the transducer can vary in any manner that responds to the pressure differential that exists near the ocean floor as a consequence of the wave action occurring at the surface. Accordingly, the invention is not intended to be limited by reference to only vertical or horizontal  
10 positioning, but in fact may be at other orientations that operate in within the inventive principles disclosed.

Referring to Figure 1, an example of the present invention is illustrated with an elongate tube 10 that provides a flow path for the water. In order to accommodate variable wavelengths of ocean waves, a telescopic configuration is provided with a  
15 second tube 12 housed within the first tube 10. It will be apparent that a single tube construction could be applied where variable wavelengths are not a significant factor. The tube length corresponds to approximately one-half wave length of the ocean wave activity, thereby positioning one tube end at a wave trough and an opposing end  
20 below a wave crest. A resulting displacement or surge of water is generated along the ocean floor corresponding to the pressure differential arising from the difference in wave height. This surge is used to power the transducer in a reciprocating manner as the crests and troughs alternate at opposing ends of the tube.

In the illustrated embodiment, a conventional electro-mechanical device 22  
such as a turbine is positioned at an intermediate location. Tube diameters are  
25 selected to provide a narrow flow channel to enhance flow speed through the electro-mechanical device 22 positioned within the flow path. To traverse the tube length, the water must pass through the electro-mechanical device, turning the internal fins of a generator, dynamo or other transducer accordingly. Such operative principles are well known and need not receive further explanation.

Figure 1 also illustrates the feasibility of both open and closed systems in the  
30 underwater environment. If the tube is an open-ended configuration, water will flow directly into the tube in a reciprocating manner, in open communication with the surrounding ocean environment. Screens may be applied at the respective openings to prevent larger aquatic life from entering the tube and interfering with the operation of

the electro-mechanical device. Alternatively, the ends can be sealed with a diaphragm as described hereafter, to prevent any foreign matter from migrating into the operating volume of the tube.

In order to increase flow rate within the tube and thus increase current output, relatively large volumes of contained water are captured at the opposing ends 14 and 16 of V the sealed version. These volumes are contained within opposing collapsible spheres, formed at the tube connection with rigid hemispheres 14 and 16, respectively coupled to flexible hemispherical diaphragms 18 and 20. These respective diaphragms are sealed at the outer perimeters 19 and 21 of the tube ends 14 and 16 to fully contain the working fluid therein. Water is introduced within the device through a valve mechanism 26 on one or both ends of the tube body.

The volume of water within the device will be a function of wave height and tube length. For example, greater wave height will allow increased force to displace more water from one tube end to the other. Therefore, maximum output would be accomplished with water volume approximately equal to the extended length of the telescopic tubes 10 and 12, plus the volume of one sphere. This configuration is illustrated in Figure 1, in which the water has been fully displaced to the left, filling the spherical structure of terminal end 14 and flexible diaphragm 18. The opposing diaphragm 20 has been fully displaced into the cavity of terminal end 16. This corresponds to the alignment of a trough above the right end 16 of the tube with force F2 bearing on the diaphragm 20, and a wave crest oriented above the left end 14, with the diaphragm 18 fully extended.

As this wave moves along the length of the device toward shore, the water height gradually shifts, causing the water to reverse direction of flow and filling the opposing end 20 as illustrated in phantom line. The successive alternate disposition of the troughs and crests over the opposing ends of the tube establish a pumping action that continuously drives the electro-mechanical device for DC current output. This current passes along a conductor 24 to a battery pack or operating load (not shown).

In view of the changing wavelength associated with wave action, a servo system is provided to position the telescopic tube 12 at a relative location to tube 10 such that the total length of the flow path is approximately one-half wavelength. This system comprises a drive motor 28 coupled to the outer tube 10 as shown. A drive

gear 32 engages a track 30 on the telescopic tube 12. Pressure sensors can be attached to the respective ends of the tube to provide a servo feed back capable of registering the proper extension of the telescopic tube 12 to reach a half wavelength. In view of the increased vulnerability to turbulence in the extended position, a vibration sensor 34 is coupled to the extended tube end to activate retraction of the extended tube if water turbulence poses a risk to the system. This extended configuration is identified in phantom line with components 16a and 20a. If wave action or adverse currents threatened the system, the driver 28 would automatically be activated to retract the tube 12 within the outer tube 10.

To further provide security and stability to the device, anchor mounts 36 and 38 are provided. These are respectively driven into the ocean floor at a separation distance equal to the length of the outer tube 10. Ground stabilizers 38 and 40 are bolted in place at the anchors to reduce migration into the ocean sand or base 46. Mounting clamps 42 and 44 engage opposite ends of the outer tube 10 and secure the tube structure in a fixed position with an orientation aligned with the direction of wave propagation. Other methods for stabilizing the device in a fixed position at the ocean floor will be apparent to those skilled in the art.

As an alternative anchor system to support posts 34 and 36, a single support 55 can be used that includes a rotational control to enable the tube to rotate or shift along a variable direction of wave movement. Accordingly, as wave direction changes, the tube would position itself substantially normal to the wave front, or at some lesser angle than 90 degrees, to optimize energy conversion.

To protect the respective diaphragm ends 18 and 20 from being damaged by extreme wave conditions, rigid grid plates 48 and 50 are attached at opposing ends of the device. These plates are sized to be slightly larger than the tube opening so that maximum displacement of the diaphragm engages the plate at the high pressure side against the opening of the tube, it against further fluid displacement. This also protects the extended lower pressure side from further displacement that might rupture the seal of the diaphragm to the rim 19 or 21. These blocking plates will allow the device to continue to operate in severe wave conditions without serious damage to the device.

Material construction for this device may utilize environmentally compatible materials known within the industry to have sufficient strength to withstand the

rigorous ocean environment. A small microprocessor can be housed within the motor drive unit 28 or within the tube body as part of the electro-mechanical device housing. This microprocessor can provide control for the telescopic displacements for wavelength and directional variations, as well as current rectification, data transmission and self-maintenance. One example of such maintenance could be a periodic full extension and retraction action to clean debris, animal and plant life from the retractable exterior. This may be timed at regular intervals, or may be sensed by irregular resistance to movement of the telescopic tube 12.

Figure 2 illustrates operation of the device with respect to an overhead wave. The wave crest 60 is momentarily located above the left side of the device 62, with a water height of  $h_c$  (crest height). The right side of the tube is oriented below the trough side 64 with a water height of  $h_t$ . The difference in height  $h_d$  provides the working force which extends downward and provides for displacement of the contained water within the tube

Figure 3 show a comparable open tube system 70 having a piston driven device 72 for generating the electrical current. The piston is coupled to a support rod 74 and coil 76 that reciprocate within a magnetic sheath 78 for production of current. The aforementioned devices are representative of closed turbine and piston systems where the transducer is contained within an enclosure. Other configurations will be apparent to those skilled in the art.

Figures 4 a, b and c depict another dimension of energy distribution within the coastal ocean wave environment, such as might be associated with an Airey wave analysis. Figure 4a shows a cross sectional view of reciprocating displacement of water along a series of flattened recirculating paths 80 at shallow depths under the overhead wave. As the wave crest moves across a volume of water, displacement of the water generates a moderate surge back and forth, a phenomenon that can be seen as sea bed vegetation is pushed too and fro on the ocean floor in response to overhead waves. Figure 4b represents this dynamic response at intermediate depths wherein the reciprocating path is represented by elliptical paths 82 having greater vertical depth.

Figure 4c illustrates a more circular path 84 occurring at substantial ocean depths where the wave forces are substantially dispersed and diminished at the depths of the ocean sea-bed. Representative depths for these illustrates might be 5 meters, 15 meters and 100 meters respectively. Based on this comparison, preferred locations for

the present invention will be a depths less than 50 meters in order to realize effective surge activity near the ocean floor.

A number of mechanical devices can be positioned at the sea-bed for interaction with this movement or surge of water. Such devices can include open  
5 turbines, vertical plates, drag bodies, and other structures that resist movement of the water in order to produce work output. These can be secured in a fixed location with a rotational hinge axis or may be displaceable along a track, as represented in the following examples.

Figure 5 depicts a transducer device 90 in which the electro-mechanical device  
10 comprises at least one plate 92 displaceable along the flow path 94 in a reciprocating manner. As water reciprocates along the flow path, the water movement urges the plate to reciprocate in like manner. The plate is coupled at a rotational axis to an electro-mechanical power conversion device 96 that translates the displacement of the plate into electric current through appropriate mechanical transmission structure to  
15 optimize current production. Each of the outputs of the plates is coupled in series through connecting wires 97 for supplying electrical current to an electrical device or battery pack 98.

Multiple plates can be positioned at separating distances  $L$  calculated to provide for cancellation of opposing forces applied to the respective plates.  
20 Specifically, plates 92a and 92b may be positioned to operate in one direction in response to flow path 94a while plates 92c and 92d displace in an opposing direction along flow path 94c. In this manner, the net force applied to the base support is at least partially cancelled, greatly diminishing lateral movement forces that would otherwise tend to cause migration of the transducer device 90. Such movement is  
25 adverse because it causes the device to settle into the sea-bed or possibly dislodge anchoring pins or structure used to secure the device in place. Determination of correct  $L$  values could be processed by a microprocessor powered by the electrical output of the device and operable to control a worm gear 95 or other lateral adjustment mechanism to develop a change  $\Delta L$  that corrects the separation distance  
30 according to overhead wavelengths. Connecting hinge plates 97 operate to maintain alignment of the multiple sections of the device.

Figure 6 shows a more specific rotational plate configuration 100 including an upper plate member 102 with extending support arms 103. Lower ends of the support



arms connect to mechanical couplings 104 that supply rotational movement to an electromechanical transducer 105 supported on the support base 106. Gearing is provided in the transducer 105 to add mechanical leverage to the input energy for optimizing electrical output through leads 108. The elevated plate 102 is positioned  
5 above sea-bed level to gain the increased force of water displacement at the higher location. A flow window 109 allows passage of water along the flow path F to sweep debris from the support base, as well as provide stability of the rotational plate within the flow path.

Figure 7 shows a second embodiment 110 with linear displacement along a track . In this case, a carriage 111 slides or rolls along a track 112 positioning a  
10 vertical plate or other resistance body 114 within the flow path 113. The length of the track is determined by the maximum half-wavelength projected for the ocean floor environment. The vertical plate 114 is rigidly fixed to the carriage and provides the resistance against water displacement. As waves pass overhead, reciprocating water  
15 surges power the transducer to generate the electrical current by rotating or translating a relative combination of coil and magnet array 117. A load, battery pack or current relay device 118 receives the current for appropriate use. Figure 7 therefore illustrates a general device wherein that includes a track 112 and tracking member 111 coupled between the track and plate 114 to enable linear displacement of the plate. Hereagain,  
20 a rotational element corresponding to element 55 of Figure could be applied to the above described track structures.

An alternative plate configuration is shown in Figure 8, wherein the device  
120 includes a plate 121 that is displaceable within the flow path, but in a rotary manner about a rotational axis 122. Specifically, the device includes a base 123 that  
25 can be anchored to the ocean floor at an appropriate location and orientation. Extending from the base is a vertical stem 124 that defines the rotational axis 122 that is vertically oriented with respect to the ocean floor. Reciprocating water surges at the ocean floor drive the plate back and forth, rotating a form of motor or electro-  
mechanical device 125 capable of translating the rotational mechanical energy into  
30 electric current. As indicated in phantom line, additional plates 127 could be coupled to the vertical stem.

Figure 9 illustrates a similar device 130 wherein the rotational axis 132 is horizontally oriented about a horizontal axis with respect to the ocean floor. The

device 130 includes a plate 131 that is displaceable within the flow path, but in a rotary manner about a rotational axis 132. Specifically, the device includes a base 133 that can be anchored to the ocean floor at an appropriate location and orientation. Extending from the base are vertical support arms 134 that support a horizontal cross arm defining the rotational axis 132 that is horizontally oriented with respect to the ocean floor. Reciprocating water surges at the ocean floor drive the plate back and forth, rotating a form of motor or electro-mechanical device 135 capable of translating the rotational mechanical energy into electric current for delivery along conductors 137.

Figure 10 illustrates an alternative mechanism for capturing the surge energy of the flow stream by use of an omnidirectional intrinsical device such as is used with wind velocity measurement. The device 140 includes a resistance unidirectional element 141 that is displaceable within the flow path, but in a rotary manner about a rotational axis 142. Specifically, the device includes a base 143 that can be anchored to the ocean floor at an appropriate location and orientation. Extending from the base is a rotational stem 144 that defines the rotational axis 142 that is vertically oriented with respect to the ocean floor. Reciprocating water surges at the ocean floor drive the plate back and forth, rotating a form of motor or electro-mechanical device 145 capable of translating the rotational mechanical energy into electric current. This embodiment could also be positioned in an underwater current to retrieve energy from a constant flow direction. This is discussed in greater detail with respect to Figures 13 and 14.

Figure 11 illustrates a mechanism for capturing the surge energy of the flow stream by use of a slave fish device. The device 150 includes a resistance foil configuration 151 that is displaceable within the flow path to generate rotary movement about a rotational axis 152. Specifically, the device includes a base 153 that can be anchored to the ocean floor at an appropriate location and orientation. Extending from the base is a rotational stem 154 that defines the rotational axis 152 that is vertically oriented with respect to the ocean floor. Reciprocating water surges at the ocean floor drive the plate back and forth, rotating a form of motor or electro-mechanical device 155 capable of translating the rotational mechanical energy into electric current.

Figure 12 illustrates an alternative mechanism for reinforcing the surge energy of the flow stream by use of an energy storage device. The device 160 includes a resistance element 161 such as a propeller or fin that is displaceable within the flow path, but in a rotary manner about a rotational axis 162. Specifically, the device includes a base 163 that can be anchored to the ocean floor at an appropriate location and orientation. Extending from the base are a pair of horizontal supports 164 upon which is suspended is rotational element 166 that defines the rotational axis 162. Reciprocating water surges at the ocean floor drive the plate back and forth, rotating a form of motor or electro-mechanical device 165 capable of translating the rotational mechanical energy into electric current. Coupled to the rotating motor 165 is an energy storage structure 167 such as an elastic coil having rotational resilience. As the moving water flows in a first direction, the propeller rotates and powers the motor 165. At the same time, the rotation of the energy storage member 167 accumulates potential energy, which can be released following passage of the overhead wave and reversal of the direction of flow. Such a combination of kinetic and potential energy may be useful in environments where the flow direction in one orientation is stronger than that of an opposing direction.

Figure 14 shows another version 170 of the anemometer of Figure 10. In this embodiment, the resistance elements 172 are hinged, concave plates that have a biased open position in which water flow 174 urges the anemometer in its rotational movement 176. Because of the hinge attachment 178 on each plate 172, water flow displaces the plate out of the flow direction from the convex side as shown with plate 172a in a deflected position. Optimal dimensions of the paddles will provide maximum surface exposure to the moving water, while maintaining a total cross-section diameter D that is less than one-half wave length of the passing waves.

Rotational movement is primarily driven by plate 172b that resists the pressure of the water movement 174 because of its open position. The other plates 172 are oriented parallel with the flow direction and assume the biased open position, offering little resistance to the flow until they are rotated into the flow path. In this manner, the anemometer is capable of continuous rotation, providing rotational motion for an attached electro-mechanical conversion device 179. It will be apparent that this embodiment will operate in a reciprocating surge environment such as with overhead ocean waves, or it can be placed in a steady current that maintains a substantially

unidirectional flow path. This configuration is therefore useful in locations of rip tides as well as regular currents along beaches or at other appropriate locations.

Based on this embodiment, the invention can be described as an energy transducer device for positioning at the ocean floor for converting water movement along a shoreline in the ocean to electrical current. The device comprises a mounting base configured for positioning at the ocean floor at a location of possible water movement along a flow path in a substantial horizontal orientation near the ocean floor; and an electro-mechanical transducer coupled to the mounting base and configured for positioning within the flow path and responsive to the water movement along the flow path to generate electrical current. The electro-mechanical transducer may include an anemometer configuration of rotational elements for providing rotational energy in response to the water movement or a drag body attached to a rotatable platform for providing rotational energy to the platform in response to the water movement.

For example, Figure 14 illustrates a collapsed configuration of the anemometer of Figure 13 wherein the respective plates 172 are reoriented to nested configuration, supported by a vertical post 173. This post can be removable from the electro-mechanical generator 179, enabling compact storage prior to deployment in the ocean. This compact size is important for marketing because the device is capable of emplacement from a small boat and/or with scuba equipment at near shore locations. Its small size and compactness facilitate transport to the installation site, as well as manipulation by a single person during installation.

An additional omnidirection embodiment 180 is represented in Figure 15, in which water flow  $F$  from any direction will apply its full force against the resistance surface. This offers the advantage of converting greater energy to electrical current because the anemometer version is essentially converting approximately one-fourth the energy of rotation in view of a single paddle 172b being the primary loaded component of the system. Specifically, in this full omnidirectional version, hemispherical dome 182 or other flow resistant body is positioned on a omnidirectional movement base such as a four bar hinged parallelogram 184. The dome 182 is coupled to one hinged corner A of the parallelogram, while one of the remaining corners O is anchored to the ocean floor. As a flow force  $F$  is applied, the

dome moves to an extreme position downstream of the flow, the four bar structure realigning itself to allow the displacement.

For example, the configuration of Figure 15a shows the dome at an upper, left-hand side. Figure 15b illustrates an applied force  $F$  coming from the left. This force would correspond to the occurrence of a wave crest above this location, initiating a water surge in direction  $F_a$ . In response to this force, the dome will shift the parallelogram support to the right as shown in Figure 15b, causing rotation around the fixed axis at  $O$  and generating electrical current into the generator 186. The parallelogram can shift locations because each of the points of attachment on the four corners are hinged as axis points, allowing 360 degree movement of the dome.

In a typical wave environment, the dome will cycle between the left and right positions in alternating fashion; however, this configuration does allow movement along any of 360 degrees of orientation. For example, Figure 15c is illustrated with a force  $F_b$  coming from the top of the page. This force urges the dome downward to a new extreme position, rotating the fixed axis  $O$  and generating current. As indicated above, this configuration is an advantage over the anemometer configuration of Figure 10 because the full force of the water movement is applied to the resistance element, rather than only to one paddle 172 of the four resistance elements. Obviously, the disadvantage of the dome embodiment is that it can only reciprocate and would not operate in a steady flow current as would the anemometer.

Although a dome version has been illustrated in Figure 15, it will be apparent that any drag object could be applied, including a cylindrical body. The fluted sides of the drag body facilitate capture of greater force from the water movement. The dome shape allows the water to flow over the device, avoiding buildup of debris around the structure.

It will be appreciated by those skilled in the art, that many variations can be applied within the operative principles of the present invention. It is intended that this disclosure not be considered limiting with respect to such inventive principles, which will be the subject of a future patent application.